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# Gravity across Space and Time

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## Abstract

How well can the standard gravity equation account for the evolution of global trade flows over the long run? This paper provides the first systematic attempt to answer this question using a newly-assembled data set of bilateral trade flows, income levels and trade frictions that spans the years from 1870 to 2005. Using this panel data set we perform a structural estimation of the gravity equation and compare the gravity-predicted trade flows with their empirical counterparts. The estimation results highlight two major puzzles: (i) the standard gravity model can explain only a small share of the variation in trade flows over time, and (ii) it requires very large time-invariant trade costs to match the average value of trade flows between country pairs. The two puzzles appear to be closely related to the assumption of a constant trade elasticity throughout the entire sample period. Allowing for modest changes in the trade elasticity across sub-periods significantly improves the time-series fit of the gravity equation and reduces to more reasonable magnitudes the time-invariant trade costs required for gravity-predicted trade flows to match the data. These findings suggest that the key to reconciling the gravity equation with the experience of globalisation history may lie in understanding the reasons for changes in the trade elasticity over time.

*JEL Classification codes:* F10, F60, N70

*Keywords:* globalisation, structural gravity, trade elasticity

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# 1 Introduction

The gravity equation has emerged as a cornerstone of the quantitative analysis of international trade flows. Over the last decades, advances in trade theory have highlighted the general conditions under which trade flows should be expected to obey a gravity equation, and shown that these apply in a wide range of modern trade models (Costinot and Rodriguez-Clare, 2014). This has bridged the gap between trade theory and a venerable empirical literature that has used the gravity equation to provide quantitative estimates for the impact of various trade determinants and policy parameters on trade flows (Head and Mayer, 2014). A key finding underpinning this literature is that the gravity equation provides a good fit for the observed variation in trade flows across space - that is, between country pairs at a given point in time. Yet, so far, there have been no formal tests of the ability of gravity to account for the long-run evolution of trade flows - that is, for given country pairs across time.

This paper provides the first systematic attempt to assess how well the standard gravity equation can match the time-series variation in trade flows since the late 19th century. Adopting this long-run perspective, we can exploit the diverse changes in trade flows and trade barriers which have taken place since the early onsets of modern globalisation, as pictured in Figure 1.

[Insert Figure 1 around here]

As the figure makes clear, the evolution of world trade (black line) and ad-valorem trade costs (grey line) since the 1870s has been far from monotonic.<sup>1</sup> While the value of trade relative to world income was fairly high in the late 19th century – reaching 7.5% on the eve of World War I –, the interwar years saw a long downward slide of the world trade ratio. Only after 1945, the world trade ratio has grown almost uninterruptedly, climbing to 12.5% by the year 2005. Also, while ad-valorem trade costs show an overall decline from 1.37 to 1.09 between 1870 and 2005, this general downward trend was frequently reversed, most notably in period around the two world wars.

To assess how well the gravity equation can account for these patterns, we assemble a panel data set on bilateral trade flows, bilateral trade frictions and income levels for the world’s major economies covering the period from 1870 to 2005. Our trade frictions data include tariffs, transportation costs and other indicators of bilateral trading environments such as fixed exchange rate regimes, free-trade agreements and on-going military conflicts. We also allow for a set of pair-specific time-invariant trade costs, so as to be able to match perfectly the average level of trade flows across country pairs. Our estimation approach differs from common panel estimations of the gravity equation in that we incorporate multilateral resistance terms which, in the spirit of

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<sup>1</sup>The black line in the figure corresponds to the ratio of imports relative to GDP - both expressed in nominal terms - for 28 large economies. The grey line is based on average tariffs and transportation costs in ad-valorem terms for the same 28 economies. More details on data sources and coverage are provided in Section 2.1 and the Appendix.

Anderson and van Wincoop (2003), obey their theory-consistent relationship with income levels and trade frictions at all points in time.

Following this approach, we uncover two puzzling results. First, between 1870 and 2005 the gravity-predicted trade flows can only account for 11% of the actual movements in trade flows within country pairs. Second, our estimation yields unreasonably large values for the time-invariant trade costs.<sup>2</sup> This is despite the fact that our estimates of the key gravity parameters are in line with earlier papers on structural gravity. Thus, the first main conclusion of our analysis is that using the best-available long-run data on trade flows and trade frictions, the standard gravity equation struggles to account for the level as well as the growth rate of global trade flows in the 1870-2005 period.

The source of the poor fit of the standard gravity equation is already visible in Figure 1. Both in the period 1870-1910 and in the period 1965-2005, average trade costs fell by approximately 10 percentage points. However, in the former period the world trade ratio rose by just 3.6 percentage points, while it increased by more than twice that number in the latter. This observation suggests an increase in the responsiveness of trade to changes in trade costs. Figure 2 illustrates this point more clearly. It plots for each year outside of the two world wars the log of the world trade ratio against the log of average ad-valorem trade costs. The three sub-periods delineated by the two world wars are distinguished by different colours. As we can see, lower average trade costs were broadly associated with a higher world trade ratio in each of the three periods; but, this association was weakest in the pre-1914 era and strongest in the years since 1945.

[Insert Figure 2 around here]

Based on this evidence, it seems plausible that allowing for some variation in the value of the trade elasticity over time may improve the fit of our gravity equation. This departure from the standard form of gravity is consistent with a number of recent theoretical trade models which imply that the trade elasticity need not be constant.<sup>3</sup> We formally test for this by estimating a more general version of our baseline specification in which the trade elasticity is allowed to vary across sub-periods. The estimation results indicate that the data strongly reject a constant trade elasticity, instead supporting a modest increase in the magnitude of the trade elasticity over time. Permitting this more than doubles the fit of our gravity-predicted trade flows within pairs and reduces the magnitude of the estimated time-invariant trade-cost parameters to more reasonable levels. This finding is robust to the country composition of our sample, the use of alternative measures of ad-valorem trade costs and the exact choice of break points for the period-specific elasticities. We take it as evidence that quantitative models which deliver endogenous changes in the trade elasticity may be better suited to account for the evolution of trade flows since the early days of globalisation.

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<sup>2</sup>While it is well known that large unobserved trade costs are required to reconcile gravity models with the observed values of trade relative to output, Anderson and van Wincoop (2004) suggest that a representative estimate of the ad-valorem equivalent of these costs is around 1.74. In our baseline estimation we find a value of 4.01.

<sup>3</sup>See, for example, Zhelobodko et al. (2012); Novy (2013); Head et al. (2014); Melitz and Redding (2015).

Our paper sits at the intersection of three distinct strands of the empirical trade literature. First, it relates to previous work that estimates the gravity equation using panel data to identify the effects of various determinants of trade on bilateral trade flows.<sup>4</sup> The papers in this literature, however, do not typically perform a structural estimation of the gravity equation which explicitly includes theory-consistent multilateral resistance terms, as we do. Instead, they employ exporter-year and importer-year fixed effects to account for them. While this approach allows for a consistent estimation of the structural parameters, mitigating the risk of an omitted-variable bias, it masks how well the gravity equation can explain the evolution of trade over time: a large portion of the time series variation in the data is simply absorbed by the (often vast) array of country-time dummies. In the present work, our emphasis on the time-series fit of structural gravity makes this approach impractical.

Second, our analysis is methodologically similar to a number of studies that have estimated gravity equations structurally using non-linear methods in order to evaluate their fit with the data and obtain values for parameters of interest.<sup>5</sup> However, these papers typically fit the gravity equation on cross-sectional data. We instead employ panel data covering a long period of time and cast the spotlight on the time-series fit of our gravity-predicted trade flows.

Third, there exists a small literature which seeks to explain the growth of world trade over time. This literature calibrates rather than estimates quantitative trade models and has focused solely on the post-1950 period.<sup>6</sup> It has shown that standard trade models – including those implying that trade flows obey a gravity equation – struggle to account for the qualitative and quantitative features of post-war trade growth. Our paper can be viewed as providing a link between this macro literature and empirical studies using gravity. While we do not calibrate but estimate the parameters of the gravity equation, we nevertheless show how well models that respect the equilibrium conditions of structural gravity at the macro level can explain the evolution of trade over time.

A key difference between ours and all the aforementioned papers is that our time-series coverage extends well beyond the post-war period to include most of the modern globalisation era. In that respect, our work relates to a buoyant cliometric literature on international trade recently surveyed by Lampe and Sharp (2015). Notable contributions in that literature include Estevadeordal et al. (2003), who assess the contribution of various trade determinants to world trade growth between

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<sup>4</sup>For example Eichengreen and Irwin (1995) analyse the role of trade blocs, Rose and van Wincoop (2001) assess the pro-trade effects of currency unions, Baier and Bergstrand (2007) study the role of trade agreements, and Head et al. (2010) investigate the role of colonial relationships. The findings of this literature have recently been surveyed by Head and Mayer (2014).

<sup>5</sup>In a seminal paper, Anderson and van Wincoop (2003) estimate a structural gravity equation using non-linear least squares in order to obtain consistent estimates of the border effect. Anderson and Yotov (2010) employ a structural gravity model in order to quantify the size and incidence of international trade costs. Baier and Bergstrand (2001) assess the contribution of different factors to trade growth between 1958 and 1988 through the lens of a semi-structural gravity estimation, with price indices proxying for the equilibrium multilateral resistance terms. Bergstrand et al. (2013) derive a theory-consistent gravity equation that allows for asymmetric trade costs and use it to obtain estimates for the trade elasticity.

<sup>6</sup>See Yi (2003), Bergoeing and Kehoe (2003), Bridgman (2008) and Zymek (2015).

1870 and 1938 through the lens of gravity, and Jacks et al. (2011), who provide a quantification of the evolution of trade costs between 1870 and 2000 by comparing actual trade flows between countries with a gravity-predicted frictionless benchmark. Our approach differs from existing work in this area as it assesses the overall fit of the gravity equation by disciplining trade costs to obey a given structural relationship, but without imposing specific values for the trade-cost parameters. This way we can gauge the size of the gap between data and gravity-predicted trade flows, and how it may be closed.

The remainder of this paper is structured as follows. Section 2 describes our data set and the structural gravity equation we use throughout the paper. Section 3 outlines our estimation approach and Section 4 presents the main results. Additional robustness checks can be found in Section 5, while Section 6 offers some concluding remarks.

## 2 Data and Theoretical Background

### 2.1 Construction of the Data Set

In order to compare the predictions of the gravity model with actual data on trade flows, we collect information on bilateral exports and imports, GDP levels, tariffs, transportation costs, and other trade frictions for the world’s major economies at an annual frequency from 1870 to 2005.<sup>7</sup> Our source for nominal bilateral trade data is Barbieri et al. (2009), while for corresponding GDP figures we combine information from the Penn World Tables for the years since 1950 with the figures of Klasing and Milionis (2014) for the earlier years. Our main source for tariffs is Clemens and Williamson (2004), while our transportation cost data are constructed by combining recent figures on maritime transportation costs from the OECD (Korinek, 2011) with the historical transportation cost index of Shah Mohammed and Williamson (2004). We also gather for each pair of countries information on the de-facto exchange rate arrangements between them, the existence of a free trade agreement, and military conflicts on an annual basis. Finally, we collect data on time-invariant factors that influence trade flows, such as pairwise distance, contiguity, shared language, and common colonial history.<sup>8</sup>

To maintain a level of consistency throughout our analysis, we focus our quantitative investigation on trade flows among major economies for which we have reasonably long time series of observations. Specifically, for most of our regressions we use a fixed sample of countries for which data on trade flows and trade frictions are available and non-zero for at least 80% of our sample period. This corresponds to 100 out of the 124 no-war years between 1870 and 2005. Moreover, we impose the additional restriction that for each of these countries we observe bilateral trade flows

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<sup>7</sup>While our data set covers also the years of the two world wars 1914-1918 and 1939-1945, in our estimations below we exclude them.

<sup>8</sup>Although the compilation of a data set covering all these variables is novel, most of the data sources we draw from have already been used in several of the aforementioned empirical studies. More details on data sources and construction of the variables can be found in Appendix A2.

with each of the other sample countries in at least one year. Based on these criteria we construct a baseline sample of 28 countries, listed in Appendix A1. These countries together reflect on average approximately 75% of world GDP over our sample period.

To ensure that our main results are not driven by this choice of sample countries, we also consider an extended sample for which we loosen the membership criteria. This includes all countries for which data on trade flows and frictions are available for a least 40 out of the 124 non-war years and for which trade flows with at least half of the possible trading partners are observed in at least one year. The combination of these two criteria leads to an extended sample of 44 countries, listed also in Appendix A1, which capture on average slightly over 80% of world GDP over our sample period.

## 2.2 The Gravity Equation

Using the data described above, we analyse how well the evolution of global trade flows can be explained by the following gravity equation:

$$\frac{M_{ijt}}{Y_t} = \theta_{ij} \left( \frac{d_{ijt}}{P_{it}P_{jt}} \right)^\sigma \frac{Y_{it}}{Y_t} \frac{Y_{jt}}{Y_t} \quad \text{with} \quad P_{it} \equiv \left[ \sum_j \theta_{ij} \left( \frac{d_{ijt}}{P_{jt}} \right)^\sigma \frac{Y_{jt}}{Y_t} \right]^{\frac{1}{\sigma}}. \quad (1)$$

Here  $M_{ijt}$  denotes nominal imports of country  $j$  from country  $i$  in year  $t$ ,  $Y_{it}$  denotes nominal GDP of country  $i$  in year  $t$ , and  $Y_t$  denotes nominal world GDP in year  $t$ . The term  $d_{ijt}$  represents the ad-valorem value of variable trade costs between countries  $i$  and  $j$  in year  $t$ . It is assumed to be symmetric ( $d_{ijt} = d_{jit} \forall i, j, t$ ) and equal to 1 within countries ( $d_{iit} = 1 \forall i, t$ ). The parameter  $\sigma < 0$  captures the responsiveness of trade flows to changes in ad-valorem trade costs, which we will simply refer to as the “trade elasticity”. The parameter  $\theta_{ij} = \theta_{ji}$  is a country-pair-specific shifter reflecting underlying factors which affect trade between countries  $i$  and  $j$  related to preferences, technology, or other bilateral time-invariant trade barriers. A key feature of structural gravity equations are the so-called “multilateral resistance terms” (MRTs), here denoted  $P_{it}$  and  $P_{jt}$ , which measure country  $i$ ’s and  $j$ ’s overall level of trade integration with the rest of the world.<sup>9</sup> As can be seen from equation (1), the MRTs depend non-linearly on trade costs, incomes and the structural parameters.

Anderson (1979) and Anderson and van Wincoop (2003) first derived equation (1) from an Armington model in which consumers have CES preferences over tradable goods that are differentiated by their country of origin. However, as is well known by now, such a functional-form relationship between incomes, bilateral trade frictions, and the value of bilateral trade can also be derived from single-sector variants of a number of quantitative trade models – including the popular Krugman-Helpman, Eaton-Kortum and Melitz-Chaney models.<sup>10</sup>

<sup>9</sup>Note that  $P_{it}P_{jt} = P_{jt}P_{it}$  given the assumed symmetry in all trade costs.

<sup>10</sup>See, for example, Costinot and Rodriguez-Clare (2014).

Given values for  $\{\theta_{ij}\}_{ij}$  and  $\sigma$ , and data on trade costs and incomes, it would be possible to use equation (1) to obtain “gravity-predicted” bilateral trade flows, which can be compared against the actual value of trade flows in any given year. Summing equation (1) over all country pairs yields a model-predicted world trade ratio – world trade flows relative to world GDP – in year  $t$ . An increase of the world trade ratio in “gravity-class” models will result either from a decline in ad-valorem trade costs or from increased similarity in countries’ shares of world GDP.

A major obstacle to testing the gravity equation described in (1) is the lack of detailed information on trade costs. In particular,  $d_{ijt}$  should encompass *all* bilateral trade costs between countries  $i$  and  $j$  at time  $t$  in ad-valorem terms. As described in Section 2.1 and Appendix A2, we compile annual ad-valorem measures of bilateral tariffs and transportation costs for all country pairs in our sample. Yet, tariffs and transport costs likely represent only the tip of the iceberg of overall trade barriers: there are many other factors – such as the absence of stable exchange rates or the lack of a common language – which are known to inhibit trade, but whose contribution to trade costs cannot be easily quantified in ad-valorem terms.

To be able to account for the effect of a broader set of time-varying and time-invariant factors on trade costs and, hence, on bilateral trade flows, we make the assumption that overall trade barriers are a log-linear function of directly measured ad-valorem trade costs and other observables.<sup>11</sup> Specifically, we assume:

$$d_{ijt} = c_{ijt} \delta_{ij} \prod_{n=1}^N (z_{ijt}^n)^{\gamma_n}, \quad (2)$$

where  $c_{ijt}$  represents ad-valorem trade costs resulting from bilateral tariffs and transportation costs between  $i$  and  $j$  in year  $t$ ,  $\delta_{ij}$  represents the contribution of time-invariant factors to trade frictions (such as  $i$  and  $j$  sharing a common language) and  $(z_{ijt}^n)^{\gamma_n}$  represents the contribution of other time-varying factors  $z_{ijt}^n$  (such as the exchange rate arrangement between  $i$ ’s and  $j$ ’s currencies). This assumption allows us to re-write equation (1) as

$$\begin{aligned} \frac{M_{ijt}}{Y_t} &= \left( \frac{\bar{\theta}_{ij} c_{ijt} \prod_{n=1}^N (z_{ijt}^n)^{\gamma_n}}{P_{it} P_{jt}} \right)^{\sigma} \frac{Y_{it}}{Y_t} \frac{Y_{jt}}{Y_t} \\ \text{with } P_{it} &\equiv \left[ \sum_j \left( \frac{\bar{\theta}_{ij} c_{ijt} \prod_{n=1}^N (z_{ijt}^n)^{\gamma_n}}{P_{jt}} \right)^{\sigma} \frac{Y_{jt}}{Y_t} \right]^{\frac{1}{\sigma}}, \end{aligned} \quad (3)$$

where  $\bar{\theta}_{ij} \equiv \theta_{ij}^{\frac{1}{\sigma}} \delta_{ij}$ .

For a sample consisting of  $I$  countries, equation (3) has  $I(I-1) + N + 1$  parameters:  $I(I-1)$  parameters capture the time-invariant trade frictions for each country pair;  $N$  parameters capture the contributions of the different qualitative measures of trade barriers to ad-valorem trade costs;

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<sup>11</sup>This assumption about the functional form of trade barriers has already been used in a number of papers on structural gravity, including Harrigan (1993), Hummels (2001), Head and Ries (2001) and Baier and Bergstrand (2001).



the trade-elasticity parameter  $\sigma$  captures the responsiveness of trade flows to changes in trade costs. Since our panel data set of bilateral trade flows, bilateral trade barriers and country incomes has a sufficiently long time dimension, it is possible to estimate the set of parameters that yield the best possible fit of equation (3) in the context of the country samples described in Section 2.1.

### 3 Estimation Approach

#### 3.1 Constant Trade Elasticity

Our estimation approach is to first treat the trade elasticity,  $\sigma$ , as a constant and estimate equation (3) in logarithms,

$$\begin{aligned} \ln \left( \frac{M_{ijt}}{Y_t} \right) &= \sigma \ln \bar{\theta}_{ij} + \sigma \ln c_{ijt} + \sum_{n=1}^N \sigma \gamma_n \ln z_{ijt}^n \\ &\quad - \sigma \ln P_{it} - \sigma \ln P_{jt} + \ln \left( \frac{Y_{it}}{Y_t} \right) + \ln \left( \frac{Y_{jt}}{Y_t} \right) + e_{ijt} \end{aligned}$$

subject to

$$P_{it} = \left[ \sum_j \left( \frac{\bar{\theta}_{ij} c_{ijt} \prod_{n=1}^N (z_{ijt}^n)^{\gamma_n}}{P_{jt}} \right)^\sigma \frac{Y_{jt}}{Y_t} \right]^{\frac{1}{\sigma}}, \quad (4)$$

where  $e_{ijt}$  is an error term. Since the MRTs in equation (4) are non-linear functions of the structural parameters, we use an iterative procedure to estimate  $\{\bar{\theta}_{ij}\}_{ij}$ ,  $\{\gamma_n\}_n$  and  $\sigma$ , the details of which are outlined in Appendix A4.

This approach differs from the standard empirical implementation of the gravity equation in a panel context which replaces the term  $-\sigma \ln P_{it} + \ln \left( \frac{Y_{it}}{Y_t} \right)$  with an exporter-year fixed effect and the term  $-\sigma \ln P_{jt} + \ln \left( \frac{Y_{jt}}{Y_t} \right)$  with an importer-year fixed effect. Following the standard approach lets the time-varying fixed effects filter out all the exporter- and importer-specific variation in the data and leaves only the pair-specific variation to be explained by gravity. Our approach, on the contrary, forces the structural gravity equation (4) to account for all observable movements of trade flows over time.

The crucial trade elasticity parameter,  $\sigma$ , is identified from observed changes in bilateral trade flows in response to changes in directly measured ad-valorem trade costs. Given an elasticity estimate,  $\gamma_n$  is estimated from observed changes in bilateral trade flows in response to changes in qualitative trade-cost determinant  $z_{ijt}^n$ . Finally, the estimates for  $\{\bar{\theta}_{ij}\}_{ij}$  ensure that the terms  $\{\sigma \ln \bar{\theta}_{ij}\}_{ij}$  absorb on average the unexplained variation in  $\ln \left( \frac{M_{ijt}}{Y_t} \right)$  and  $\ln \left( \frac{M_{jit}}{Y_t} \right)$  across country pairs.<sup>12</sup>

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<sup>12</sup>Trade is bilaterally balanced in the gravity equation, which is evident from equation (1):  $M_{ijt} = M_{jit} \forall i, j, t$ . However, this is generally not the case in the data. In our estimation we treat  $\ln \frac{M_{ijt}}{Y_t}$  and  $\ln \frac{M_{jit}}{Y_t}$  as two different observations to be explained by the same realisations of right-hand-side parameters and variables in (4). This is the same as artificially “balancing” trade flows by regressing on the single observation  $\frac{1}{2} \ln \frac{M_{ijt}}{Y_t} + \frac{1}{2} \ln \frac{M_{jit}}{Y_t}$ .

### 3.2 Time-Varying Trade Elasticity

Having first treated it as a constant, we subsequently allow the trade elasticity parameter to vary over time. This choice is motivated by the evidence described in the introduction as well as by recent theoretical contributions in the literature which stress that small deviations from standard assumptions in trade models imply trade elasticities that may not be constant.<sup>13</sup>

We split our sample period into three sub-periods, the period prior to WWI (1870-1913), the interwar period (1919-1938) and the post-WWII era (1946-2005), and let the trade elasticity take distinct values in each period.<sup>14</sup> Thus, we now estimate the following more general version of equation (4):

$$\begin{aligned} \ln \left( \frac{M_{ijt}}{Y_t} \right) &= \ln \left( \frac{Y_{it}}{Y_t} \right) + \ln \left( \frac{Y_{jt}}{Y_t} \right) \\ &+ \sigma \left( \ln \bar{\theta}_{ij} + \ln c_{ijt} + \sum_n \gamma_n \ln z_{ijt}^n - \ln P_{it} - \ln P_{jt} \right) \\ &+ \sum_{s=1,2} \zeta_{T_s} \left( \ln \bar{\theta}_{ij} + \ln c_{ijt} + \sum_n \gamma_n \ln z_{ijt}^n - \ln P_{it} - \ln P_{jt} \right) + e_{ijt}, \end{aligned}$$

subject to

$$P_{it} \equiv \left\{ \sum_j \left[ \frac{\bar{\theta}_{ij} c_{ijt} \prod_n (z_{ijt}^n)^{\gamma_n}}{P_{jt}} \right]^{\sigma + \zeta_{T_s}} \frac{Y_{jt}}{Y_t} \right\}^{\frac{1}{\sigma + \zeta_{T_s}}}, \quad (5)$$

where

$$\zeta_{T_s} = \begin{cases} \Delta \sigma_{T_s} & \text{if } t \in T_s \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

and letting  $T_1 \equiv \{1919, \dots, 1938\}$  and  $T_2 \equiv \{1946, \dots, 2005\}$ . Note that (5) and (6) imply that we only allow the trade elasticity parameter to vary across time periods, while all other estimation parameters  $\{\bar{\theta}_{ij}\}_{ij}$ ,  $\{\gamma_n\}_n$  are treated as constant throughout. This way we can assess (i) whether the data support changes in the value of the trade elasticity over time, and (ii) whether these changes in the trade elasticity *alone* can improve the time-series fit of the gravity equation.

### 3.3 Time-Invariant Trade Costs

Our estimate of the parameters  $\{\bar{\theta}_{ij}\}_{ij}$  can be thought of as capturing the ad-valorem-equivalent value of unobserved time-invariant trade costs. Econometrically, these parameters act as country-pair fixed effects, with  $\sigma \ln \bar{\theta}_{ij}$  absorbing most of the variation in bilateral trade flows across country

<sup>13</sup>For example, a variable trade elasticity can emerge in models where consumers' love for variety depends on the level of consumption (Zhelobodko et al., 2012), consumer preferences are translog (Novy, 2013), or firm productivities do not follow a Pareto distribution (Head et al., 2014; Melitz and Redding, 2015).

<sup>14</sup>We omit the years during which the world was engulfed in WWI (1914-1918) and WWII (1939-1945).

pairs.<sup>15</sup> We place no further restrictions on  $\{\bar{\theta}_{ij}\}_{ij}$ , as we would like to allow our gravity equation to match the average value of trade flows relative to incomes across pairs and separate this from the ability of the gravity equation to explain the over-time evolution of trade. However, it is instructive to compare the resulting magnitudes of our time-invariant trade-cost parameters with alternative estimates from the literature in order to assess their plausibility. Such a comparison is performed in Section 4.3.

Since our country-pair fixed effects represents the product of the trade-elasticity parameter  $\sigma$  with the log of time-invariant bilateral trade costs  $\bar{\theta}_{ij}$ , the implied ad-valorem magnitude of the latter will hinge on our estimate of  $\sigma$ . This implies that for a given “between” variation in bilateral trade flows, that is given estimates for  $\{\sigma \ln \bar{\theta}_{ij}\}_{ij}$ , a larger  $\sigma$  lead to smaller  $\{\bar{\theta}_{ij}\}_{ij}$ . The economic intuition is straightforward. With a greater responsiveness of trade flows to changes in trade frictions, smaller time-invariant trade costs are needed to explain the average value of trade for any country pair.

## 4 Main Results

### 4.1 Constant Trade Elasticity

The first two columns of Table 1 present the estimation results when the trade elasticity ( $\sigma$ ) is treated as a constant. In column (1), we only use our ad-valorem measures of tariffs and transportation costs to capture time-varying trade costs (i.e. we impose  $d_{ijt} = c_{ijt}\delta_{ij}$ ). In column (2), we also use dummy variables to control for the effect of fixed exchange rate arrangements, the presence of free trade agreements, and on-going military conflicts on bilateral trade costs over time (i.e.  $d_{ijt}$  is given by equation (2)). In both cases, the estimation yields values of the trade elasticity very close to those found in other studies using only post-WWII trade data:  $-4.69$  in column (1), and  $-4.45$  once we use the additional trade-cost controls in column (2).<sup>16</sup>

[Insert Table 1 around here]

The coefficients on each of the three trade-cost indicator variables in column (2) represent their estimated contributions to log trade costs ( $\gamma_n$ ). In order to ascertain their effects on trade flows, the reported coefficients need to be multiplied with the trade elasticity. For example, having a fixed exchange rate is estimated to reduce ad-valorem trade costs by 4%, and thus, to increase trade flows by  $(-4.45 \times -4 =) 18\%$ . In qualitative terms, the coefficients on all three trade-cost dummies have the expected sign and are statistically significant.<sup>17</sup> Bilaterally fixed exchange rates and free

<sup>15</sup>If trade flows were balanced in the data,  $\sigma \ln \bar{\theta}_{ij}$  would absorb all the “between” variation in bilateral trade flows. See also Footnote 12.

<sup>16</sup>For comparison, the mean value of the trade elasticity from 622 theory-consistent gravity estimations performed in the existing literature is 5.13. See Table 3.5, p. 164, in Head and Mayer (2014).

<sup>17</sup>The standard errors in all our regressions are quite small confirming the good empirical fit of the gravity equation.

trade agreements are found to reduce trade frictions, and hence, to increase trade, while military conflicts are found to do the opposite. Quantitatively, these are in line with estimates found in previous studies.<sup>18</sup> Therefore, despite the fact that we use panel data with a significantly longer time dimension, our regressions yield parameter estimates consistent with the existing literature.<sup>19</sup>

Unlike previous econometric studies, however, our structural estimation allows us to provide a more stringent assessment of the fit of the standard gravity equation with the data. As shown in the bottom of columns (1) and (2), the overall  $R^2$  of our structurally estimated gravity equation is high, with over 60% of the variation in the data explained by our estimated model. Yet, this masks large differences between the cross-sectional (“between”) and the time-series (“within”) fit of gravity. While our estimation accounts for most of the “between” variation in the data, it captures only 11% of the “within” variation. This stark contrast between the fit of the gravity model across space and across time constitutes our first main finding: With a constant trade elasticity and using the best-available data on ad-valorem trade costs and other trade barriers between 1870 and 2005, the standard gravity equation provides a poor fit of the evolution of global trade flows over time.

Note that existing work estimating gravity equations based on panel data typically reports a good fit of the data, contrasting the poor time-series fit uncovered here. This apparent discrepancy with the existing literature is due to the fact that our estimation procedure computes the multilateral resistance terms explicitly based on actual data on incomes, ad-valorem trade costs and the estimated trade-cost parameters. Thus, our multilateral resistance terms only capture variation due to observed factors. This is in contrast to the more standard practice in the literature of employing exporter-year and importer-year fixed effects that absorb all the country-specific variation in the data – including variation due to unobserved factors – and hence “patch” part of the potential mismatch between data and gravity-predicted trade flows along the time-series dimension.

The shortcomings of the predictions derived from a gravity equation with a constant trade elasticity are illustrated graphically in the panel (a) of Figure 3. In this panel, the evolution of the world trade ratio implied by our structurally-estimated gravity equation from column (2) is plotted against its real-world counterpart. As the graph makes clear, the time-series fit between the prediction and the data is far from perfect, with the root mean-squared error of the prediction amounting to 36% of the average world trade ratio. In particular, the gravity model appears to under-predict the value of trade flows relative to world GDP in the pre-WWI period, as well as the extent of the growth in trade flows relative to world GDP after WWII. In other words, imposing a constant trade elasticity for the period 1870-2005, the gravity equation struggles to reconcile the high volume of trade prior to WWI in the face of high trade costs with the strong response of trade flows to modest declines in trade frictions after WWII.

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<sup>18</sup>See Table 3.4, p. 160 in Head and Mayer (2014).

<sup>19</sup>We do not report estimates of the coefficients on the log of countries’ shares of world GDP –  $\ln(Y_{it}/Y_t)$ ,  $\ln(Y_{jt}/Y_t)$  – and the multilateral resistance terms –  $\ln P_{it}$ ,  $\ln P_{jt}$  – since these are constrained to equal 1 and  $\sigma$ , respectively. For a discussion of the properties of the estimated time-invariant trade-cost parameters, see Section 4.3 below.

[Insert Figure 3 around here]

## 4.2 Time-Varying Trade Elasticity

Column (4) in Table 1 reports the results of the estimation with a time-varying trade elasticity. We find strong support in the data for a modest increase in the absolute value of trade elasticity across sub-periods. Moreover, the “within” fit of the gravity equation more than doubles, from .11 in column (2) to .25 in column (4), raising the overall  $R^2$  by 10%. Perhaps surprisingly, however, the estimation also yields much larger magnitudes for the trade elasticity in each of the three sub-periods than we obtained for the whole period in column (2).

The flip-side of the rise in the magnitude of the trade elasticity throughout is that smaller time-invariant bilateral trade costs are required for the model to fit the cross-section of the data. This can be seen at the bottom of each column in Table 1 where the median estimated value of the time-invariant bilateral trade cost parameters  $\bar{\theta}_{ij}$  from the respective regression is reported. Comparing these median values between the constant-elasticity estimation – column (2) – and the time-varying-elasticity estimation – column (4) – we find that in the latter case these values are halved compared to the former. Thus, permitting the trade elasticity to vary across our main sub-periods improves the fit of the standard gravity equation along two dimensions: i) the within-pair over-time variation in trade flows explained by the model rises significantly, and ii) the average level of trade flows between country pairs can be matched with lower time-invariant bilateral trade costs.

The reasons why the estimation with a time-varying trade elasticity both improves the time-series fit of the gravity equation and raises the magnitude of the trade elasticity throughout can be understood by returning to panel (a) of Figure 3. In the figure, the slope of the gravity-predicted world trade ratio is governed mostly by the estimated trade elasticity, since variable trade costs are the most important driver of over-time changes in trade flows in our estimation. Meanwhile, the average level of the predicted world trade ratio is governed by a weighted average of the time-invariant trade cost parameters,  $\bar{\theta}_{ij}$ , *raised to the power  $\sigma$* . For any  $\sigma$  the estimated  $\bar{\theta}_{ij}$  parameters will adjust to match the average value of predicted trade flows. Hence, loosely speaking, a rise in  $\sigma$  would tilt the red-dashed line in panel (a) of Figure 3 around its mean point and at the same time trigger a fall in the  $\bar{\theta}_{ij}$  values. Thus, there is a tension in determining the appropriate value of  $\sigma$  to reflect the evolution of world trade as seen in the data. A high absolute value of  $\sigma$  would capture trade *growth* in the pre-WWI and post-WWII periods well, but would result in an underprediction of the pre-WWI *level* of world trade. A low absolute value of  $\sigma$  would lead to the reverse outcome. The time-invariant elasticity parameter estimated in column (2) reflects a compromise between these alternatives.

Once the elasticity is allowed to vary over time, this tension is resolved: high values of the trade elasticity throughout more closely reflect observed trade growth within periods, while the relatively high *level* (and low growth!) of trade in the period 1870-1913 is accounted for through

a relatively low absolute value of  $\sigma + \zeta_{T_1}$ . The resulting improvements in the time-series fit of the gravity equation are clearly visible in panel (b) of Figure 3. This panel plots the predicted world trade ratio from column (4) against its real-world counterpart. Throughout the entire sample period, the gravity predictions now more closely reflect the data, and the root mean-squared error is reduced by 17% relative to the average trade ratio.

In order to disentangle the effects of the period-to-period changes in the trade elasticity from the rise in its magnitude in all periods and corresponding fall in  $\{\bar{\theta}_{ij}\}_{ij}$ , in column (3) we report the results from an “intermediate” estimation. In this estimation, we constrain the time-invariant trade costs to equal the values obtained in the estimation shown in column (2), but allow the trade elasticity to vary across the three sub-periods as in column (4). Note that, with the time-invariant trade costs pinned down, we would not expect the average value of the estimated period-specific trade elasticities in column (3) to veer far from our column-(2) estimate – otherwise the model would over- or underpredict the average values of bilateral trade flows. The estimation results confirm this expectation, with the period-specific trade elasticities ranging from  $-4.22$  to  $-4.47$ . However, just as in column (4), we find that the estimation supports a modest increase in the magnitude of the trade elasticity over time. The  $R^2$  in column (3) suggests that this generalisation of our column-(2) specification alone, with given time-invariant trade costs, raises the within-fit of our prediction by 60%.

### 4.3 Time-Invariant Trade Costs

Beyond comparing the within-pair fit of the gravity equation between the cases of a constant and a variable trade elasticity, it is also instructive to inspect the estimated magnitudes for the time-invariant trade costs,  $\{\bar{\theta}_{ij}\}_{ij}$ , in ad-valorem terms. These parameters are included in our gravity estimation to capture differences in the average value of bilateral trade flows across pairs of countries. Contrasting their magnitudes with other estimates of time-invariant trade costs from the literature provides information on how well our gravity equation can explain the cross-sectional variation in trade flows.

Using the baseline sample of 28 countries our estimation yields  $(28 \times 27/2 =)$  378 parameters capturing the magnitudes of the time-invariant component of bilateral trade frictions. The distribution of these parameters is displayed in Figure 4 both for the constant-elasticity estimation of column (2) and for the time-varying-elasticity estimation of column (4). In both cases the distribution is skewed towards the right, as estimated time-invariant trade costs are quite high for a few pairs. A simple comparison of the medians of the two distributions, however, reveals that the values obtained in the latter case are significantly lower than in the former. The lower values obtained in the time-varying-elasticity case imply that the gravity equation can match the cross-sectional variation in trade flows by attributing less to unobserved trade frictions. These values also appear more reasonable with the median value of 80 percent being close to the figure found by Anderson and van Wincoop (2004) in their survey of gravity-estimated trade costs.

[Insert Figure 4 around here]

An alternative way to assess the plausibility of our estimated values for  $\{\bar{\theta}_{ij}\}_{ij}$  is to consider how well they can be explained by the usual time-invariant determinants of trade costs considered in the literature. This way we can relate our analysis to a large body of research that seeks to identify the factors that generate trade barriers across space. In the remaining part of this section we demonstrate that our estimated bilateral trade-cost parameters are consistent with this literature in that these parameters match some of the key empirical regularities identified therein.

To show this, we regress our estimate of  $\ln \bar{\theta}_{ij}$  on a set of time-invariant trade-cost determinants. These include the log of distance, and indicator variables for spatial contiguity, for sharing a primary language and for the existence of a colonial relationship. The results are shown in Table 2. Column (1) of Table 2 reports the results of the simple regression, while the regression reported in column (2) adds country dummies to the specification. All coefficient estimates have the expected sign: distance between countries is found to increase bilateral trade costs (thus reducing trade), while contiguity, a common language, and the existence of a colonial relationship are found to reduce trade costs (thus increasing trade). With the exception of the coefficient on contiguity, all estimates are statistically significant. The inclusion of country dummies changes the coefficient estimates little, but raises the  $R^2$  from .28 to .61.

[Insert Table 2 around here]

Using our post-WWII trade elasticity from column (4) of Table 1 ( $-9.01$ ) and the coefficient estimates from column (2) of Table 2, the implied elasticity of trade flows with respect to distance is  $-.81$ , while a common border, a common language, and colonial ties appear to boost trade by 54%, 126% and 72%, respectively. With the exception of the language coefficient, which is somewhat large, these values are very close to the values reported in the meta-analysis of structural gravity regressions by Head and Mayer (2014).<sup>20</sup> The variation in our estimates of time-invariant trade costs thus appears to be explained well by the usual time-invariant determinants of trade costs and to gel with findings in the existing literature.

## 5 Robustness Checks

In this section, we show through a number of robustness checks that our baseline results are not driven by our choice of sample countries, our measure of ad-valorem trade costs, and the exact delineation of our sub-periods.

A possible concern regarding our main estimation results is the fairly limited country coverage in our sample. As discussed in Section 2, our baseline sample only includes 28 countries in an attempt to strike a balance between maximising country coverage and minimising the share of observations

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<sup>20</sup>See Table 3.4, p. 160, in Head and Mayer (2014).

for which bilateral trade flows are either missing or zero. To ensure that our results are not driven by this specific group of countries, we repeat our estimation using the above described extended sample which covers 44 countries. Table 3 reports the results.

[Insert Table 3 around here]

A cursory glance at Table 3 reveals that the main conclusions which emerged from Table 1 are robust to extending the number of countries in our sample. As before, the constant-elasticity gravity estimations - in columns (1) and (2) - yield a poor “within” fit of the data. The fit improves again significantly when we allow for changes in the elasticity between the three main sample periods in columns (3) and (4). As with the smaller sample, our estimations using the large sample yield an increase in the trade elasticity from period to period in column (4), and a much higher (average) trade elasticity than in columns (1) and (2), underpinned by much smaller estimates of the time-invariant trade-cost parameters. The only differences between Tables 1 and 3 are that we find somewhat larger values for the trade elasticity in the latter and that the sign of the coefficient capturing the effect of bilaterally fixed exchange rates is reversed.<sup>21</sup>

Given our focus on the trade elasticity and noting that this parameter is identified from the empirical response of trade flows to variations in directly measured ad-valorem trade costs, it seems natural to question whether our findings are robust to changes in our preferred measure of those costs. In particular, our ad-valorem trade costs combine information on tariff levels - which have been used in previous empirical studies - with a measure of bilateral transportation costs we constructed ourselves from cross-sectional data and long-run time trends in shipping costs. In the first part of Table 4, we check whether our findings are altered if we exclude our measure of transportation costs and use tariffs as the *only* direct measure of ad-valorem trade costs. Columns (1) and (2) in Table 4 correspond to columns (2) and (4) in Table 1. They show that omitting transportation costs raises the estimated value of the trade elasticity in the constant-elasticity estimation but, other than that, has no significant impact on our results.

[Insert Table 4 around here]

As a last robustness test, we explore whether our finding of a rising response of trade flows to changes in trade costs is an artefact of our choice of the sample break points. While the two World Wars would seem to constitute natural breaks in our sample period, it is also evident from Figure 3 that the various structural gravity regressions struggle most to account for the time-series evolution of trade during the interwar period. In columns (3) and (4) of Table 4, we therefore present coefficient estimates for a time-varying-elasticity estimation with a single break point, in which the interwar period is alternatively allocated either to the “early” or “late” part of the sample period. A comparison between column (4) of Table 1 and columns (3) and (4) of Table 4 makes

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<sup>21</sup>Recent empirical research using a large sample of countries for the post-WWII period suggests that the effect of currency unions on bilateral trade is extremely heterogeneous across currencies (Eicher and Henn, 2011). This may explain why this coefficient is sensitive to the country composition of the sample.



clear that this does not significantly affect our findings, neither qualitatively nor quantitatively. In all cases we clearly obtain an elasticity that is (i) time-varying, and (ii) increasing in absolute value over time.

## 6 Concluding Remarks

In the present paper, we assess the ability of the standard structural gravity equation to account for the evolution of global trade flows over time, starting from the late-19th century. Using the best-available long-run data on trade flows, trade frictions and income levels, we show that the gravity equation derived from a range of quantitative trade models struggles to account for observed variation in bilateral trade over time and can only match the variation across pairs with unrealistically high time-invariant trade costs. At the same time, we demonstrate how the fit of gravity across time and space can be substantially improved once we allow the trade elasticity to vary across sub-periods. Our more general estimation that allows for this leads to an estimated trade elasticity that increases modestly over our sample period. The “within”- $R^2$  of this estimation is twice that of the benchmark estimation with constant elasticity and the predicted trade volumes match the average between-pair differences in trade flows without requiring unrealistically high time-invariant trade costs.

At first glance our main findings may appear sobering. It would be a triumph for trade theory indeed if the standard gravity equation were able to account for most of the behaviour of global trade since 1870. Our results suggest that in order to give a full quantitative account of the history of trade globalisation, it may be necessary to move beyond the standard version of the structural gravity equation. Yet, we also find that small departures from the standard framework may be sufficient to give the gravity equation a better chance of explaining the evolution of trade flows over the long run. Our evidence highlights that one such departure could be empirically plausible changes in the magnitude of the trade elasticity over time.

There are several reasons why the trade elasticity may not have been constant throughout the last 150 years of history. For one thing, different “gravity-class” trade models provide different structural interpretations of the trade elasticity and, hence, potentially different values for this parameter. An observed change in the value of the trade elasticity over time may thus simply reflect changes in the nature of global trade, and hence, in the nature of the most appropriate model to explain it. Moreover, even for a given “gravity-class” trade model, several recent papers explore settings in which straightforward generalisations of standard assumptions about preferences (Zhelobodko et al., 2012; Novy, 2013), technologies (Head et al., 2014; Melitz and Redding, 2015), intermediate-goods linkages (Yi, 2003) or sectoral structure (Ossa, 2015) can lead to an aggregate trade elasticity which changes endogenously with the magnitude of trade barriers. Based on the evidence provided here, pushing the frontiers of “gravity-class” models may hold the key to understanding the ups and downs of world trade since the early days of globalisation.

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# Appendix

## A1: List of Countries

Baseline Sample Countries			
Argentina	Egypt	Mexico	Sri Lanka
Australia	France	Netherlands	Sweden
Brazil	Germany	New Zealand	Thailand
Canada	Greece	Norway	Turkey
Chile	India	Philippines	United Kingdom
China	Italy	Portugal	United States
Denmark	Japan	Spain	Uruguay
Additional Extended Sample Countries			
Cyprus	Malawi	Russia	Uganda
Ghana	Malaysia	Switzerland	Yugoslavia
Guyana	Myanmar	Tanzania	Zambia
Kenya	Nigeria	Togo	Zimbabwe

## A2: Data Sources

Our source for bilateral trade data is Barbieri et al. (2009). They provide data on both exports and imports, all measured in current-price US dollars, starting in 1870.<sup>22</sup> We focus on the import data, which are more detailed and more reliable. We pair these trade data with corresponding GDP figures, also in current-price US dollars from Klasing and Milionis (2014) for the years before 1950 and from Penn World Tables afterwards.<sup>23</sup> To fill in the few gaps in the import and GDP series, we interpolate missing values assuming a constant growth rate. This allows us to work with a relatively balanced sample of countries.<sup>24</sup>

Our main source for tariff data is Clemens and Williamson (2004). Their data cover the period between 1870 and 1998. We extend the data to 2005 using more recent information from the World Development Indicators.<sup>25</sup> For the years prior to 1913 we also supplement the data with additional information from Schularick and Solomou (2011). All sources report tariff in the form of average rates for each importing country in ad-valorem terms. Following the literature, we construct bilateral tariff rates by taking the mean of the average tariff for each pair of countries.

Our data on ad-valorem transportation costs are also pair-specific and are constructed combining recent information on maritime transportation costs from the OECD (Korinek, 2011) with

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<sup>22</sup>We choose this data set because of its comprehensive nature in terms of both country and year coverage compared to alternative data sources.

<sup>23</sup>Klasing and Milionis (2014) use the "short-cut" method to obtain nominal GDP figures for the pre-1950 period for the countries covered in the Maddison data.

<sup>24</sup>It should be emphasised that the interpolated data constitute only a share of 6.8% in our baseline sample.

<sup>25</sup>This is the same source that Clemens and Williamson used for the post-1950 period.

the historical transportation cost index of Shah Mohammed and Williamson (2004). The details of how the data are constructed are presented in Appendix A3 below.

To capture the exchange rate arrangement between each pair of countries we use the classification provided by Ilzetzi et al. (2011). We treat two countries as having a fixed exchange rate arrangement if according to this source the two countries either used the same legal tender or had their currencies fixed together or fixed to the same third currency in the form of a pre-announced peg, a de facto peg, a currency board arrangement, or a pre announced band narrower than or equal to  $\pm 2\%$ .

For information on active free trade agreement we rely on Baier et al. (2014) for the years after 1950 and supplement their data with information from Pahre (2008) and Kohl et al. (2015) for the earlier years.

To account for military conflict we use the data set of Sarkees and Wayman (2010), which report all wars fought since 1810, and construct an indicator for all pairs of countries fighting on different sides of the same war.

Finally, we rely on the GeoDist database (Mayer and Zignago, 2011) in order to obtain for each pair of countries information regarding the geodesic distance between their largest cities, whether they are contiguous on the map, whether they share an official language, and whether they have ever been in a colonial relationship.

### A3: Construction of Transportation Cost Data

Our starting point in order to obtain pair-specific transportation costs for all our sample countries is the OECD Maritime Transport Cost database (Korinek, 2011). The database reports information on transportation costs for different industries from 218 exporting to 43 importing countries for various years. As these data are subject to a lot of measurement error, we follow Hummels and Lugovskyy (2006) and construct a predicted value of pairwise transportation costs from a regression of actual costs on the distance between each country pair and the weight-value ratio of imports (all expressed in logarithms). Using the data for 2007 and taking an average value across all manufacturing industries delivers the following regression estimates for a sample of 1,175 pairs with the  $p$ -values for the coefficients reported in brackets:<sup>26</sup>

$$\ln(Ad.Val.Tr.Cost) = \underset{[0.000]}{-2.518} + \underset{[0.007]}{0.056\ln(Distance)} + \underset{[0.000]}{0.363\ln(Weight/Value)}$$

To ensure consistency with the assumption made in our gravity estimation we impose symmetry in our transportation costs. For this purpose we take average values for the actual transportation costs and the weight-value ratios whenever different information is available from the two sides.

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<sup>26</sup>We pick 2007 as this gives us the largest sample size and is the most recent year for which the data are available. We also focus on manufacturing goods shipped in containers, which makes the bulk of international shipping. Adding agricultural and other products would distort the estimation results because of their perishability and limited tradability.

Based on this regression we predict transportation costs for the largest possible set of countries given the information available on weight-value ratios in the OECD dataset. For country pairs where this information is missing in 2007, we use the weight-value ratio from the year closest to 2007. Doing so allows us to obtain transportation cost estimates for 2,242 pairs of countries.

To capture the evolution of transportation costs over time we combine our obtained pair-specific values for transportation costs with the global transportation cost index constructed by Shah Mohammed and Williamson (2004). Their original index covers the period 1870 to 1997 and is available in 5-year intervals. To allow for year-by-year variation, we expand the index by attributing each reported value to the mid-point of the interval and interpolate the remaining values assuming a constant annual growth rate for the years in between. The index is also extended to the year 2007 by extrapolating based on the average growth rate observed during the 1990s. This choice can be justified by the monotonic decline of transportation costs during those years, reported by Hummels (2007), which was not reversed at any point until the global financial crisis.

## A4: Estimation Procedure

Our objective is to estimate the parameters  $\sigma$ ,  $\{\bar{\theta}_{ij}\}_{ij}$  and  $\{\gamma_n\}_n$  using the equation

$$\begin{aligned} \ln\left(\frac{M_{ijt}}{Y_t}\right) &= \sigma \ln \bar{\theta}_{ij} + \sigma \ln c_{ijt} + \sum_{n=1}^N \sigma \gamma_n \ln z_{ijt} \\ &- \sigma \ln P_{it} - \sigma \ln P_{jt} + \ln\left(\frac{Y_{it}}{Y_t}\right) + \ln\left(\frac{Y_{jt}}{Y_t}\right) + e_{ijt} \end{aligned}$$

s.t.

$$P_{it} = \left[ \sum_j \left( \frac{\bar{\theta}_{ij} c_{ijt} \prod_{n=1}^N (z_{ijt}^n)^{\gamma_n}}{P_{jt}} \right)^\sigma \frac{Y_{jt}}{Y_t} \right]^{\frac{1}{\sigma}}.$$

To do so, we employ the following procedure:

1. “Guess” some initial values  $\sigma^0$ ,  $\{\bar{\theta}_{ij}^0\}_{ij}$  and  $\{\gamma_n^0\}_n$ .
2. Use the parameter values to calculate  $\{P_{it}^0\}_{it}$ .
3. Estimate

$$\begin{aligned} &\ln\left(\frac{M_{ijt}}{Y_t}\right) - \ln\left(\frac{Y_{it}}{Y_t}\right) - \ln\left(\frac{Y_{jt}}{Y_t}\right) + \sigma^0 \ln P_{it}^0 + \sigma^0 \ln P_{jt}^0 = \\ &\sigma^1 \Delta \ln \bar{\theta}_{ij}^1 + \sigma^1 \sum_{n=1}^N \Delta \gamma_n^1 \ln z_{ijt} + \sigma^1 \left[ \ln \bar{\theta}_{ij} + \ln c_{ijt} + \sum_{n=1}^N \gamma_n \ln z_{ijt} \right] + e_{ijt}^1. \end{aligned}$$

4. Calculate a new set of parameter values:  $\sigma^1$ ,  $\{\bar{\theta}_{ij}^1 = \Delta \bar{\theta}_{ij}^1 + \bar{\theta}_{ij}^0\}_{ij}$  and  $\{\gamma_n^1 = \Delta \gamma_n^1 + \gamma_n^0\}_n$ .
5. Repeat steps 2.-4. until  $\sigma^s = \sigma^{s-1}$ .

Figure 1: Evolution of Trade Flows and Trade Frictions, 1870-2005

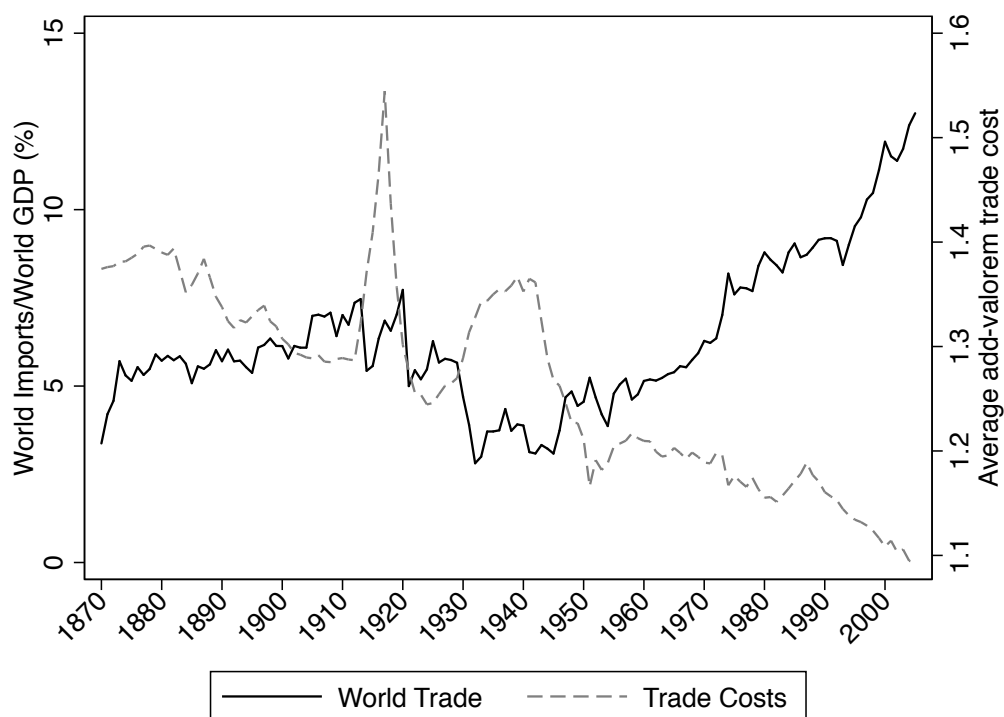


Figure 2: Responsiveness of Trade Flows to Trade Frictions, 1870-2005

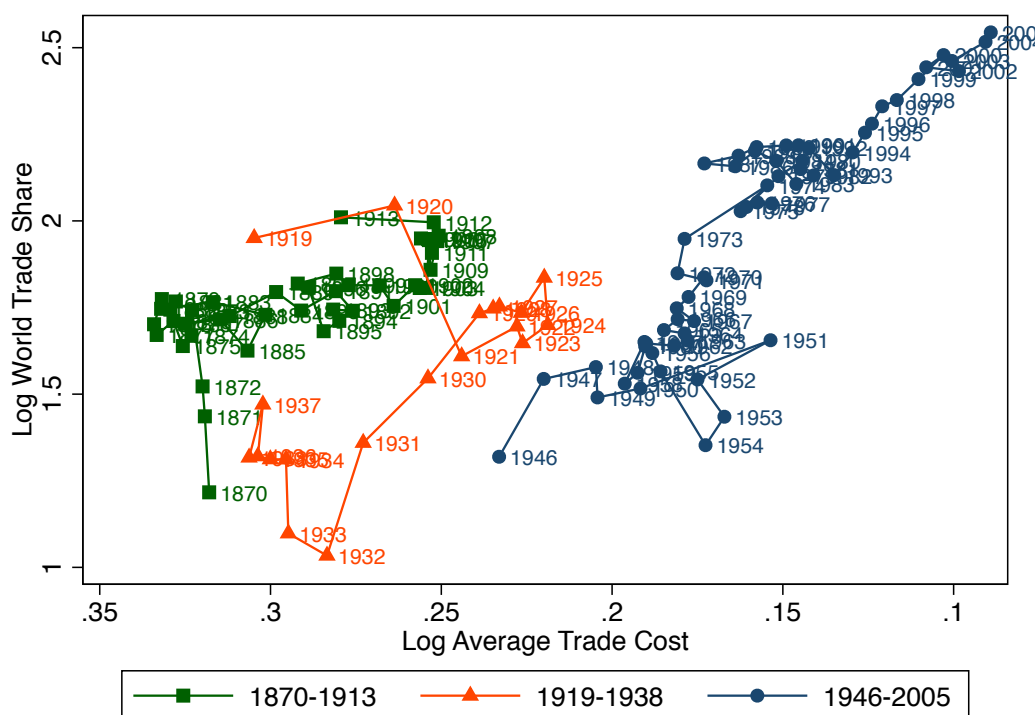
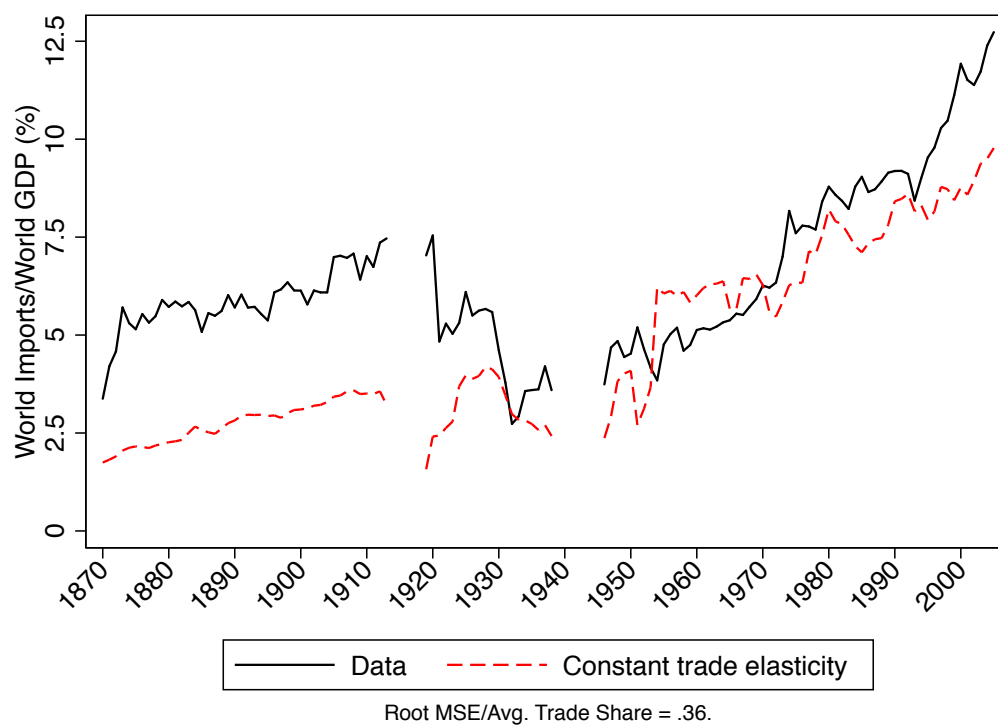




Figure 3: Actual versus Model-Predicted World Trade Ratio, 1870-2005

Panel (a)



Panel (b)

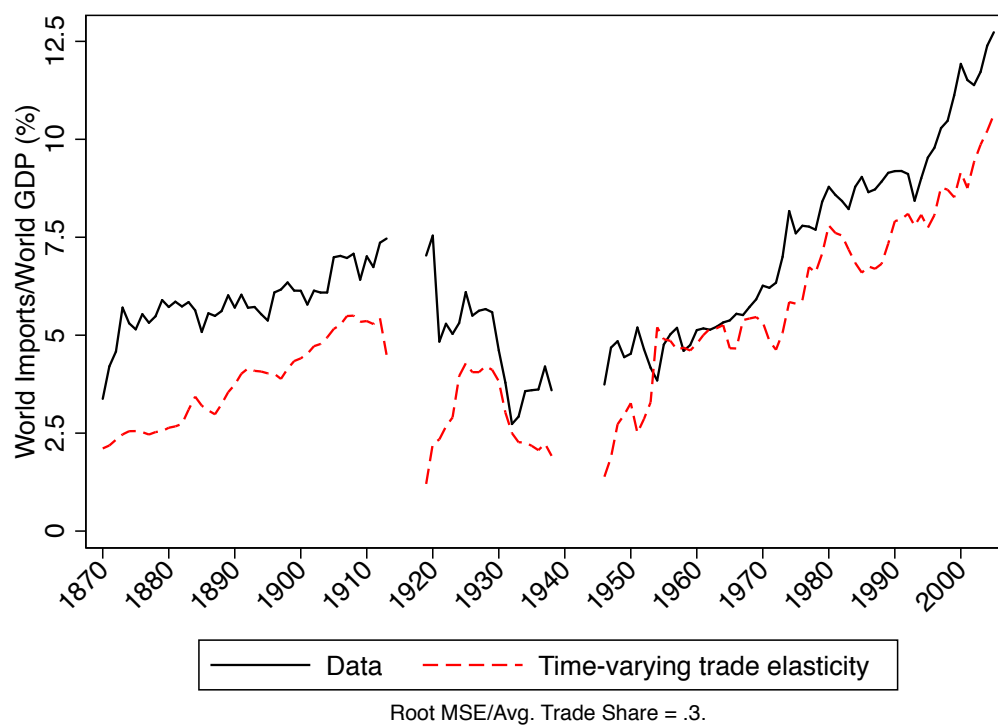


Figure 4: Estimated Time-Invariant Trade Frictions

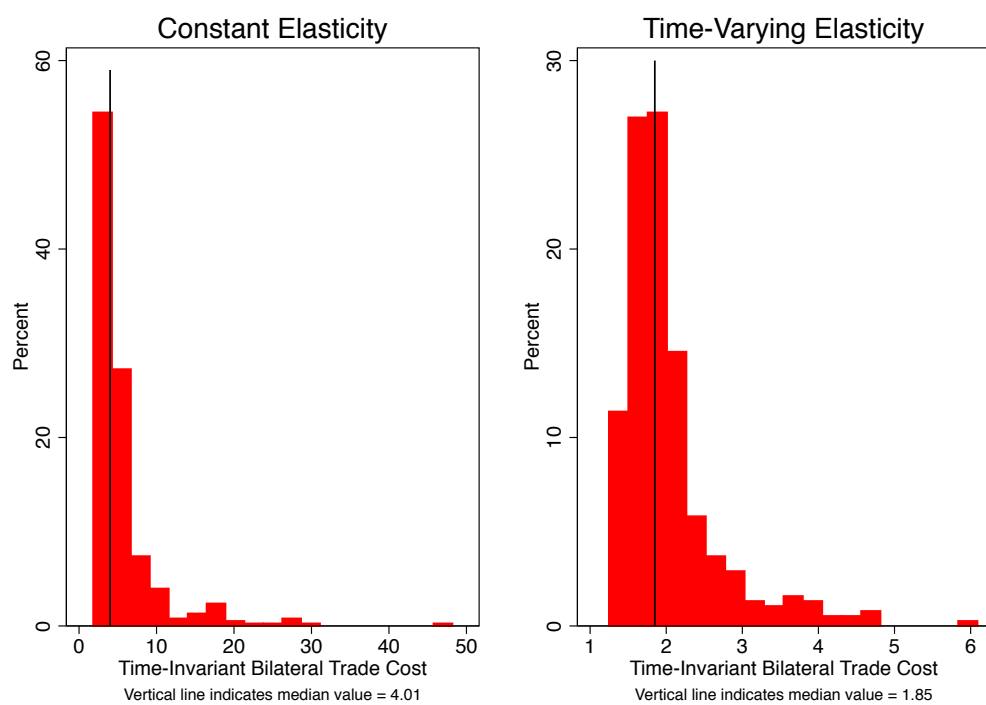


Table 1: Main Regressions

Main Table

Dependent variable: log bil. trade flows

	(1)	(2)	(3)	(4)
Trade elasticity	-4.69 (0.01)***	-4.45 (0.01)***	-4.22 (0.02)***	-8.30 (0.03)***
+ $\Delta$ elasticity (1914-1945)			-0.27 (0.02)***	-0.34 (0.04)***
+ $\Delta$ elasticity (1946-2005)			-0.25 (0.02)***	-0.71 (0.03)***
Common currency/peg: log $\Delta$ trade costs		-0.04 (0.01)***	-0.02 (0.01)***	-0.01 (0.00)***
Free trade agreement: log $\Delta$ trade costs		-0.07 (0.01)***	-0.08 (0.01)***	-0.04 (0.00)***
Ongoing war: log $\Delta$ trade costs		0.08 (0.07)	0.13 (0.08)*	0.07 (0.04)*
Observations	49,414	49,414	49,414	49,414
Median time-invariant bil. trade cost	3.69	4.01	4.00	1.85
$R^2$ :				
- overall	.62	.63	.67	.69
- between	.92	.92	.92	.92
- within	.08	.11	.18	.25

\*  $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\*  $p < 0.01$ 

Note: Estimates of GDP coefficients, MRTs and pair time-invariant trade costs not reported.

Table 2: Determinants of Time-Invariant Trade Frictions

Determinants of time-invariant bilateral trade costs

Dependent variable: log ad-valorem time-inv. bil. trade costs

	(1)	(2)
Log distance	0.13 (0.01)***	0.09 (0.01)***
Common border: log $\Delta$ trade costs	-0.02 (0.05)	-0.06 (0.06)
Common language: log $\Delta$ trade costs	-0.14 (0.03)***	-0.14 (0.04)***
Colonial relationship: log $\Delta$ trade costs	-0.14 (0.04)***	-0.08 (0.05)*
Country dummies	No	Yes
Observations	378	378
Adj. $R^2$	0.28	0.61

\*  $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\*  $p < 0.01$ 

Note: Robust standard errors in parentheses.

Table 3: Robustness Regressions I: Extended Sample

Robustness 1: Large Sample  
Dependent variable: log bil. trade flows

	(1)	(2)	(3)	(4)
Trade elasticity	-6.11 (0.01)***	-5.74 (0.01)***	-5.37 (0.02)***	-9.92 (0.05)***
+ $\Delta$ elasticity (1914-1945)			-0.40 (0.04)***	-0.51 (0.06)***
+ $\Delta$ elasticity (1946-2005)			-0.39 (0.03)***	-1.00 (0.05)***
Common currency/peg: log $\Delta$ trade costs		0.05 (0.00)***	0.07 (0.00)***	0.03 (0.00)***
Free trade agreement: log $\Delta$ trade costs		-0.01 (0.01)*	-0.02 (0.01)***	-0.02 (0.00)***
Ongoing war: log $\Delta$ trade costs		0.05 (0.06)	0.10 (0.07)	0.05 (0.04)
Observations	71,686	71,686	71,686	71,686
Median time-invariant bil. trade cost	2.92	3.13	3.12	1.71
$R^2$ :				
- overall	.61	.6	.64	.68
- between	.92	.92	.93	.92
- within	.07	.07	.11	.2

\*  $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\*  $p < 0.01$

Note: Estimates of GDP coefficients, MRTs and pair time-invariant trade costs not reported.

Table 4: Robustness Regressions II: Different Trade Frictions and Break Points

Robustness 2: Trade Costs, and Break Points  
Dependent variable: log bil. trade flows

	(1) Tariffs only	(2) Tariffs only	(3) period 1 = 1946- 2005	(4) period 1 = 1914- 2005
Trade elasticity	-6.53 (0.01)***	-8.04 (0.03)***	-7.90 (0.02)***	-6.15 (0.02)***
+ $\Delta$ elasticity (period 1)		-0.21 (0.04)***	-0.46 (0.02)***	-0.43 (0.03)***
+ $\Delta$ elasticity (period 2)		-0.34 (0.03)***		
Common currency/peg: log $\Delta$ trade costs	-0.02 (0.00)***	-0.01 (0.00)***	-0.02 (0.00)***	-0.01 (0.00)***
Free trade agreement: log $\Delta$ trade costs	-0.05 (0.01)***	-0.06 (0.00)***	-0.04 (0.00)***	-0.05 (0.01)***
Ongoing war: log $\Delta$ trade costs	0.06 (0.05)	0.07 (0.04)	0.06 (0.04)	0.08 (0.05)
Observations	49,414	49,414	49,414	49,414
Median time-invariant bil. trade cost	2.64	2.09	1.95	2.43
$R^2$ :				
- overall	.66	.70	.66	.68
- between	.92	.92	.92	.92
- within	.17	.28	.16	.24

\*  $p < 0.1$ ; \*\*  $p < 0.05$ ; \*\*\*  $p < 0.01$

Note: Estimates of GDP coefficients, MRTs and pair time-invariant trade costs not reported. Period 1 is 1914-1945, and period 2 is 1946-2005, unless otherwise indicated.